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OFDM-based Micro-Signal Communication Method for the Spherical Amphibious Underwater Vehicle

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***Abstract* – The micro-signal communication technology for the underwater vehicle is one of the important components of robot. With the rapid development of spherical amphibious robot, many high-tech scientific research institutions and universities around the world are studying the development and application of underwater robot. Recently, RF (radio frequency) has been widely adopted in the field for distant wireless communication. The OFDM (Orthogonal Frequency Division Multiplexing) method is a better way in signal transmission. As a kind of multi-carrier OFDM modulation technology, this method contains high frequency utilization, suitable for high speed data transmission and narrowband interference, etc.**

This paper proposed the OFDM modulation mode in the process of controlling the spherical amphibious robot. OFDM technology is able to decrease signal fading, which is suitable for distance information transmission in underwater robot. We carried out simulation experiments, with LS channel estimation and without channel estimation algorithm. The simulation results indicated that when added LS channel estimation in simulation experiment, it can effectively reduce the bit error rate, on the other hand, the simulation without LS channel estimation, bit error rate decreases relatively slowly. OFDM modulation method is a kind of mode in radio frequency communication module, which greatly decreased the bit error rate and maintain the signal transmission.

Index items - Amphibious Spherical robot, OFDM(Orthogonal frequency division multiplexing), DAQ(Data acquisition card), LabVIEW

I. INTRODUCTION

The amphibious robot can make researches and discoveries in the bottom of the sea for investigation, identification and salvage operations of both economic research and security care. Military amphibious robot also can be an effective weapon under water. Spherical amphibious robot has advantages with safe and simple structure, light weight, small size. And compared with a remote underwater vehicle (ROV) [1][2], it has a wider range of activities, diving depth, the robot can enter the complex structure, without the aid of a large surface. Automatic underwater robot represents future development direction of underwater robot technology, and it is a hotspot of current research work around the world.

Robotics is a concentration of kinematics and dynamics theory, mechanical design and manufacturing technology, computer hardware and software technology, control theory, and the theory of artificial intelligence, science and technology for the integration of comprehensive technology. Its research and development marks a national science and technology development level, and its widespread application in the field of all kinds of machinery, shows the power of the national economy and the development of science and technology. In order to promote their development career, many countries focus more on robot. The development of industry and military can not live without the innovation of the robots [3][4].

Spherical amphibious robot in the wireless control still needs to implement further research, by making spherical amphibious robot wireless control analysis, these method control signals are superimposed by using OFDM modulation, this paper proposed can effectively way to multi-robot remote control, it also can reduce the bit error rate (BER) in a large extent. Using OFDM signal superimposed on transmission mode in the robot control, is a kind of effective method, and this is the trend to our research, the program of waveform provide by the LabVIEW software.

Wave transmitted by OFDM modulation and simulated signal waveform on the computer, through the data acquisition card, it converts digital signals into analog signals and transmitted through the RF radio frequency module.

Due to the new technology involved is not mature enough, with high failure rate of the electronic equipment, communications matching issues and lifting recovery, the communication research between multiple underwater robots is becoming more significant, and spherical amphibious robot control is becoming significant more important, some control method will be carried out to make the robot move and do some actions, under these communication system, we should pay attention to the signal transmission among multi-robots.

Based on the spherical robot research, a new concept was put forward. A spherical amphibious robot which swims in the water can walk on land, and achieve barrier-free travel, in the land, rivers, lakes, sea environment such as data acquisition, signal transceiver, etc [5].

According to the new communication method, we can enhance the real time of signal transmission ， which sent to the robot at the same time. Through the base station shown in the Fig.1, it describes the control center send two different frequency control signals at the same time to control the amphibious robots.

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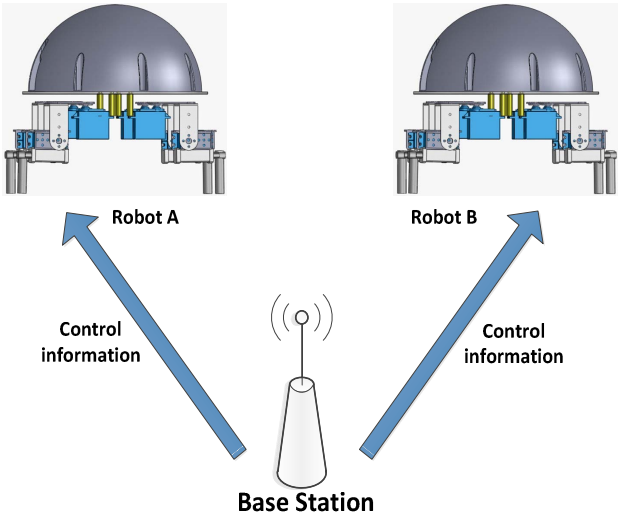

Fig. 1 The conceptual diagram for multi-robot communication

Further more, the robot can do free rolling both on land and underwater, at the same time can also move in the water. The spherical robot is a enclosed, zero turning radius of the mobile platform, which can be fitted with a camera or other sensors in the land, rivers, lakes, sea researches, salvage, rescue and military missions, therefore enlarge the using range of the spherical robots. First, according to the proposed amphibious spherical robot mechanism, this paper is based on the structure type of the driving mechanism of spherical robot design. Second, this paper carries out the amphibious on land and underwater spherical robot kinematics and dynamics analysis and motion control research [7]. Third, according to the requirements of the amphibious function of spherical robot, this paper puts forward the overall design scheme of amphibious spherical robot control system, divides the control system which contains control subsystem and execution subsystem, sensor subsystem, communication subsystem, power subsystem and upper machine system. The basic components of each subsystem are analyzed.

This paper proposes an OFDM-based micro-signal communication method for the spherical amphibious vehicle, LabVIEW is used to create micro low frequency waveform, this waveform can be treated as a control signal. Orthogonal frequency division multiplexing has good resistance to multi-channel features, and the characteristics of the high bandwidth utilization. We use error correction coding method in underwater OFDM modulation system [8][9].

II. The System Structure

The paper mentioned control system structure includes the following several aspects, LabVIEW software, DAQ card, and NRF905 radio frequency mode. The receiver part in the spherical amphibious robot contains RF mode, AVR develop board and actuators, when control signal transmitted to AVR, it can use PWM to control actuators.

With the process of signal transmission in electronic communication, a signal must be first collected and then loaded to the sending device. The original information can be received by dealing with the collected signal with the receiver. This process can be generalized by the general model of transmit systems, we use LabVIEW to modulate several ultra low waveform, through the mode VISA, this part of LabVIEW can modulate different frequency wave, the last send it to the RF buoys after modulation in DAQ card. These structure is shown in Fig.2.

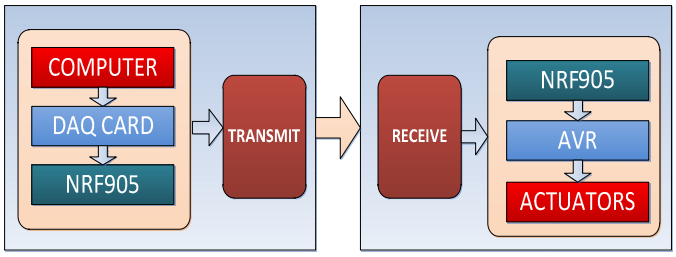

Fig. 2 The transmitter and receiver system

A. *The structure of the amphibious robotic system*

The spherical amphibious robot has several components, including AVR ATMEGAA2560, water-jet propellers, servo motors, battery module etc. AVR ATMEGAA2560 is selected for the microcontroller of the spherical robot, which can control eight motors and four water-jet propellers. The microcontroller has eight PWM signals for controlling servo motor to realize walking motion on land, another four PWM signals are used to control the water-jet propellers. The prototype of spherical amphibious robot is shown in Fig.3.

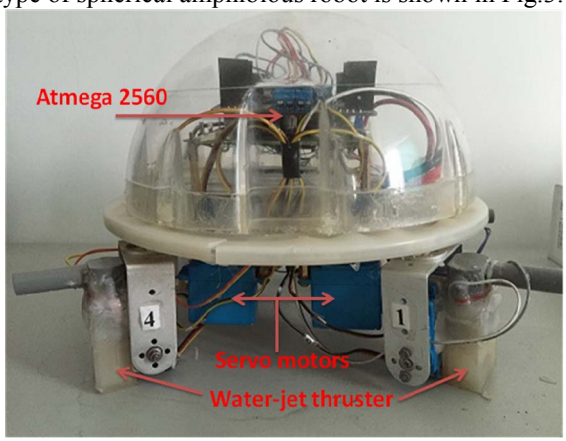

Fig. 3 The prototype of the spherical amphibious robot

B. *The waveform signals created by LabVIEW software*

By introducing LabVIEW software widely used in virtual instrument program design, it illustrated the advantages of graphical integration development platform, and points out its advantages after compared with traditional programming language. And the waveform generator is given to the basis of hardware using LabVIEW to write drivers and portable.

Waveform occurred through LabVIEW software, which is a kind of signal source, relatively widely applied in the modern communication field, this is one of the methods in the research, just like production, testing, control and maintenance of various electronic components, parts and whole equipment colleagues. Different waveform voltage produced by the

frequency, to analyze their performance parameters. The LabVIEW software is used to produce control waveform signal, it is a novel means of accused of robots, using this method can effectively reduce the signal attenuation in the process of transmission problems.

Through the LabVIEW software, the graphical interface is designed, and the output of the low frequency signal is easy to operate and the low frequency signal waveform is shown in the interface as shown in the Fig.4.

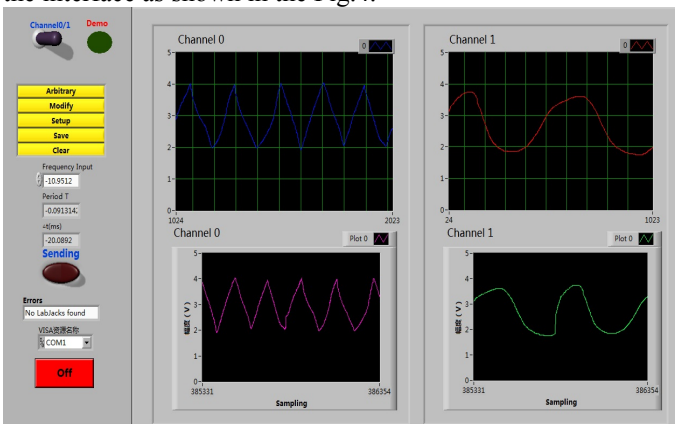

Fig.4 The waveform created by LabVIEW

C. The program of low frequency waveform module

The period of the buffer is T and the frequency is f. Program execution time is 20ms, $T = 2^{10} \times 0.02s = 20.48s$ $f = \frac{1}{20.48} \approx 0.0488Hz$, Assuming at least 10 points to determine a waveform, then $10 = \frac{2^{10}}{Cycle}$, The number of the output waveform is 10, so the sampling number is 1024.

Behind graphical interface program is the frame program, The front panel provided waveform display scope, buttons and the frequency of a periodic input device, these components will be constructed and connected in the frame program. The frame program can become a trend in the process of the virtual instrument editing, and it will be more useful. The underlying block diagram program can visually shows the program's transport processes, graphical interfaces, and easy operation of software to give us great convenience. During the development of LabVIEW software, it also encounters many problems, including the programming conduction and the problem of loading of the driver.

The low-frequency signal waveform generation system controlled by graphical underlying program, including the channel 0 and channel 1, when we chose the a channel, then added in draw signal waveform of the underlying process, using it while the program structure selection, input waveform storage in an array for later use. The block diagram of the map is shown in Fig.5.

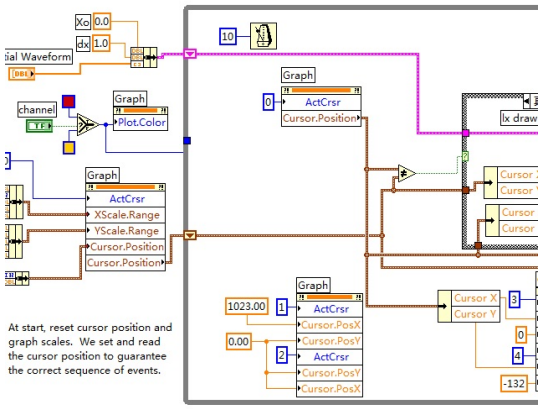

Fig.5 The program of waveform generation

Drew the new VI(virtual instrument) for the output waveform, connected it to the while loop register and used to store boxing of value, in order to achieve a new waveform storage and transmission. At the same time, isolated waveform array elements in it and connected to one-dimensional array indicator for wave shaped data output.

The VI design mainly included the following several parts. The waveform data, rendering the direction, calculation of starting point location, and the starting point of overflow processing. The VI design mainly included the following several parts. The conditional terminal is false, indicating that the mouse position has not be changed, we only need the original waveform directly through the case structure, and a boolean value false constantly as the output channel connected to the case frame, this way indicated the program can be treated as a mark of waveform refresh. We can know about the program from the Fig.6.

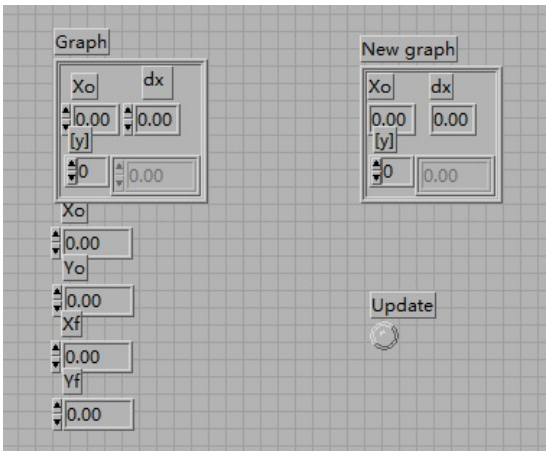

Fig. 6 The VI of drawing new point

D . The application of the OFDM algorithm

Binary frequency transmitted digital information by using the change of frequency of the carrier transmission. In 2 PSK [12] [13], carrier frequency and the binary baseband signal change between f1 and f2, amplitude control is used for transmission of digital information of carrier wave and kept frequency and initial phase unchanged.

The time domain expressions of signal can be written as:

$$e_{2FSK}(t)=\left[\sum_n a_n g(t-nT_s)\right]\cos(\omega_1 t+\varphi_n)+\left[\sum_n \overline{a_n} g(t-nT_s)\right]\cos(\omega_2 t+\theta_n) \quad (1)$$

For binary FSK signal, the maximum output SNR (Signal-to-Noise Ratio) can be get. According to this principle, optimal receiver principle block diagram used binary FSK signal composed of the matched filter. The system structure diagram is shown in Fig.7.

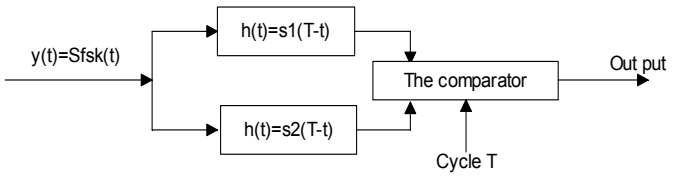

Fig. 7 FSK signal transmission process

E. The equation of calculating spectrum

The unit impulse response solution could help the linear system and time domain characteristics to analyze the former signals. The connection between the output signal and the input signal, and the equation is shown as in Fig.8.

$$u_0(t)=\int_0^t h(\tau)u_i(t-\tau)d(\tau) \quad (2)$$

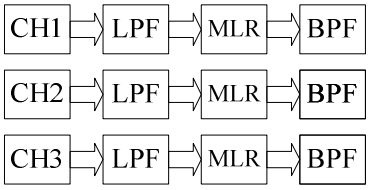

Fig. 8 The steps from input signal to the output signal

TABLE I
APPLICATION AND COMPARISON OF VARIOUS MODULATION SYSTEM

Modulation method	Transmission bandwidth	S_0/N_0	Use field
AM	$2f_m$	$\left(\frac{S_0}{N_0}\right)_{AM}=\frac{1}{3}\left(\frac{S_i}{n_0 f_m}\right)$	Medium wave radio
DSM	$2f_m$	$\left(\frac{S_0}{N_0}\right)_{DSB}=\left(\frac{S_i}{n_0 f_m}\right)$	Less use
SSB	f_m	$\left(\frac{S_0}{N_0}\right)_{SSB}=\left(\frac{S_i}{n_0 f_m}\right)$	Voice communication
VSB	Slightly larger than f_m	Similar to SSB	Television and radio
FM	$2(m_f+1)f_m$	$\left(\frac{S_0}{N_0}\right)_{SSB}=\frac{3}{2}m_f^2\left(\frac{S_i}{n_0 f_m}\right)$	Stereo radio

In the field of underwater communication technology, remote transmission of instructions and commands, or the process of high-speed information, transmission is found to practical solutions, and there are a large number of experimental systems and the experimental results as bedding. Under the application of OFDM modulation method, the waveform is transmitted to the controlled terminal, this method can effectively reduce the bit error rate, so we will use this transmission method in the direction of underwater robot control, it can be controlled through low-frequency waveform of underwater robot. This low frequency waveform is better to reduce signal collapse, relative to the traditional control signal. The application of OFDM transmission system model is shown in Fig.9.

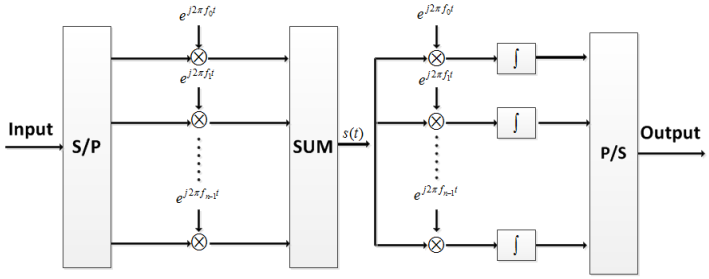

Fig. 9 The transmission model of OFDM

In order to improve the utilization of channel and the pick-up the signal, a number of signals should be transmitted through one channel. Between the code and carrier modulation formula, Δf is the frequency interval. The addition of the carrier signal obtains the actual launch of OFDM signal $X(t)$.

$$f_n=f_0+\Delta f \quad (3)$$

$$\Delta f=\frac{1}{N\cdot T_a} \quad (4)$$

$$X(t)=\sum_{K=0}^{N-1}X(k)\exp(j2\pi f_k t) \quad (5)$$

The multipath signal is needed in frequency division multiplexing modulation in advance to the frequency of different position, and then sent the waveforms to the same channel transmission. Frequency division multiplexing signal on the spectrum that overlaps in time domain can be sent at the same time.

OFDM is built on the basis of the principle of FDM, and carrier set used two orthogonal waves sine and cosine function. Referring to various messages with different frequencies, FDM and OFDM can be used in order to realize multiplex communication. This method is also called frequency reuse. Radio and television broadcasting are most familiar and the most obvious example of frequency division multiplexing.

$$\int_0^{t_0+T}\cos n\omega t\cdot\cos m\omega t dt=\begin{cases}0 & (n\neq m)\\ T/2 & (n=m)\quad T=2\pi/\omega\\ T & (n=m=0)\end{cases} \quad (6)$$

The subcarrier signals are irrelevant. As long as the signals are synchronized, they will become orthogonal signals after modulating. Theoretically, the receiver could use

orthogonality for demodulation. The OFDM signal equation is:

$$S(t) = \sum_{n=1}^{N-1} f_n \cos(\omega_n t) \tag{7}$$

III. Simulation Results

We used the waveform editing panel to draw a set of low-frequency signal waveform, and gave this signal a function, the function is a kind of control signal. The waveform editor is LabVIEW software, LabVIEW connected to data acquisition card, and edited the waveform signal through the data acquisition card of D/A function, modified the digital signal into an analog signal and showed it on the oscilloscope. The experiment results are shown in Fig.10.

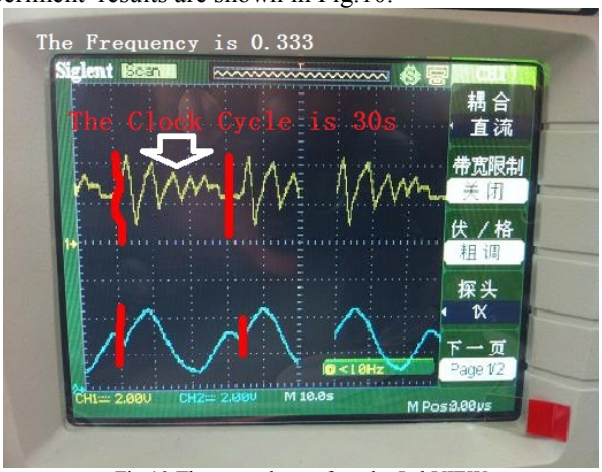

Fig.10 The control waveform by LabVIEW

Using LabVIEW editing generates low-frequency signal waveform to achieve control signals of the amphibious robot. This innovative point of the method used in waveform generated by the low frequency communication system, it relatively reduced the noise function better, and effectively decreased the bit error rate (BER).

In order to solve the synchronization or resistance to multipath interference, OFDM symbol need to insert a period of protection. The protection time is not empty, but a symbol of the back part on the front is a protection. This is called protective prefix. This protection with circulatory system, and used to prevent such multipath inter symbol interference.

OFDM communication system include some of channel estimation algorithms, including time domain channel estimation algorithm and frequency domain channel estimation algorithm.

According to the signal processing in time domain and frequency domain, the LS algorithm also can be divided into time domain and frequency domain methods. Based on the OFDM modulation, we used the LS channel estimation method to simulate OFDM modulation system, and carried out two simulation experiments, with LS(Least-square) channel estimation and without LS channel estimation. The experimental results were shown in Fig.11.

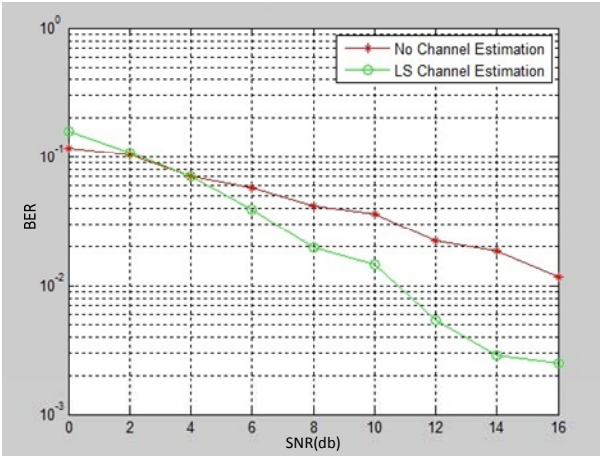

Fig.11 The LS channel estimation for BER.

The simulation results indicated that LS channel estimation could decrease the BER(Bit error rate) effectively than without LS channel estimation. When processing of underwater low noise related problems, we can use the LS channel estimation algorithm, to achieve a relatively lower complexity and lower BER.

IV. Experiments and Results

When sending the LabVIEW signals from control system to amphibious robot, this process should be divided into several narrow sub-band signals to transmit in parallel through adjusting the frequency of FDM bandwidth. But in order to avoid interference among each subcarrier, it has to retain a larger interval in adjacent subcarrier, which greatly reduces the spectrum efficiency.

The control system is based on the LabVIEW software development platform, in need of content, we can use mouse to draw the arbitrary waveform to build program block diagram, and edited the drawing of the waveforms, creating active interface, and making waveform frequency adjustment in time. Transmission signal control system has three parts, the first is respectively with the LabVIEW software of computer, second is data acquisition card, and the last is radio frequency module, we used oscilloscope instead of RF module to test the integrity of the output waveform. LabVIEW control system experiment shown as in Fig.12.

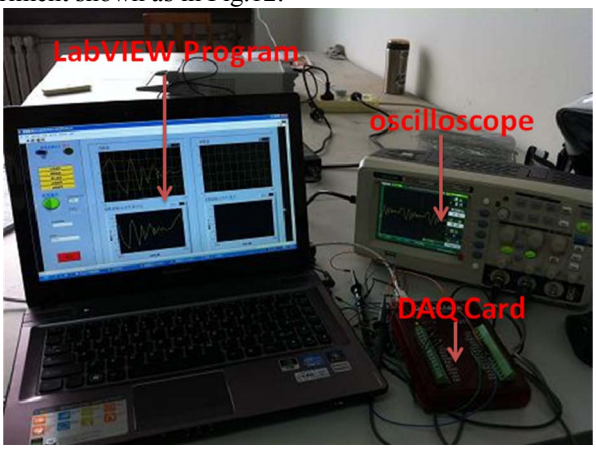

Fig.12 The components of control system

V. Conclusion And Future Work

In this paper, we proposed a conceptual method for OFDM-based communication, OFDM modulation method is a kind of mode in radio frequency communication, which greatly reduced the bit error rate and maintain the signal transmission.

Firstly, we superimposed the waveform in OFDM method. After OFDM modulation we used DAQ card output analog waveform, and modulated it into control signals. In the end, we carried out two simulation experiments, the simulation results indicated that when added LS channel estimation in simulation, it can effectively reduce the bit error rate. On the other hand, without LS channel estimation, bit error rate decreased relatively slowly. The simulation results indicated that OFDM modulation method is a kind of mode in radio frequency communication module, which greatly reduce the bit error rate and maintain the signal transmission.

In the future, we will use the OFDM modulation in multi-robot communication system.

Acknowledgments

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References

[1] J.H.Li, J.T.Kim, M.J.Lee, H.J.Kang, "Conceptual Design of Optimal Thrust System for Efficient Cable Burying of ROV Trencher," R&D Center for Underwater Construction Robotics, KIMST, Korea, 2014.

[2] Nima Harsamizadeh Tehrani, Mahdi Heidari,etc., "Developlent, Depth Control and Stability Analysis of an Underwater Remotely Operated Vehicle(ROV)" IEEE International Conference on Control and Automation, Vol 2, pp.814-819, June 9-11.2011.

[3] German,C.R., Jakuba, M.V., Kinsey, J.C. "A long term vision for long-range ship-free deep ocean operations:Persistent presence through coordination of Autonomous Surface Vehicles and Autonomous Underwater Vehicles," Autonomous Underwater Vehicles (AUV), pp.1-7.2012.

[4] Arjuna Balasuriya, Stephanie Petillo,etc., "Behavior-Based Planning and Prosecution Architecture for Autonomous Underwater Vehicles in Ocean Observatories," 77 Massachusetts Avenue, Cambridge, MA 02139, USA. Vol 2, pp.1-5, 2010.

[5] Shuxiang Guo, Maoxun Li, Chunfeng Yue, "Performance Evaluation on Land of an Amphibious Spherical Mother Robot in Different Terranin," IEEE International Conference on Mechatronics and Automation August4-7, Takamatsu, Japan, pp.1173-1178, 2013.

[6] Pete Alleman, Art Kleiner, Development of a New Unmanned Semi-Submersible (USS) Vehicle", C&C Technologies, Inc. vol. 2, pp.1-6, 2009.

[7] Shuxiang Guo, Zixin Zhao, "An Acoustic Communication System for Multiple Underwater Vehicles Based on DS-CDMA"IEEE International Conference on Information and Automation, Zhuhai/Macau, June 22-25,pp.318-323, 2009.

[8] Chin-Feng Lin, Zhen-Xiang Shi, Shung-Hyung Chang,. "A Power Assignment Mechanism for OFDM-based Underwater Acoustic Communication System," Department of Electrical Engineering, National Taiwan-Ocean University, vol 1, pp.1545-1548. 2009.

[9] Xinchuan Lin, Shuxiang Guo, Yanling Hao. "A Simplified Dynamics Modeling of a Spherical Underwater Vehicle," IEEE International Conference on Robotics and Biomimetics, Bangkok Thailand, vol 1, pp.1140-1145, February 21-26. 2009.

[10] Dražen Jurišić, "Systems for Analog and Mixed Signal Processing in Integrated Technology Based on Network Theory," KEYNOTE SPEAKERS, Faculty of Electrical Engineering and Computing, University of Zagreb, Croatia.pp.2-4. 2014.

[11] Chengbing He, Jiangguo Huang, Qunfei Zhang, etc. "Reliable Mobile Underwater Wireless Communication Using Wideband Chirp Signal," International Conference on Communications and Mobile Computing, Xi'an, Shaanxi, 710072, China. Vol.3, pp.146-150. 2009.

[12] G.de Valicourt, M.A.Mestre, H.Mardoyan, J.C.Antona, "Ultra-Compact Monolithic Integrated InP Transmitter at 224Gb/s with PDM-2ASK-2PSK modulation," OFC Postdeadline, Optical society of America, 2014.

[13] Mostafa El-Khamy, Jinhong Wu, Jungwon Lee, "Near-Optimal Turbo Decoding in Presence of SNR Estimation Error," IEEE, Signal Processing for Communications Symposium, pp.3737-3742, 2012.